U. S. AIR FORCE

PROJECT RAND

RESEARCH MEMORANDUM

TRANSMISSION OF PULSES
OVER VOICE-QUALITY TELEPHONE LINES

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Assigned to ______________________

The RAND Corporation
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Transmission of Pulses over Voice-Quality Telephone Lines

The transmission of pulse-type signals is important in many applications. Where the required information rate is low it is possible to use a narrow-band transmission link. The availability of voice-quality telephone lines makes their use desirable wherever they are capable of handling the signals. The purpose of this memorandum is to examine the pulse-handling capability of such telephone lines.

The frequency response of the prototype telephone line used in the study is shown in Fig. 1. The line used was approximately 150 miles long. The response of the line to a step function is shown in Fig. 2 and to a short pulse (1/8 ms) in Fig. 3 (these were sketched from oscilloscope traces).

The RAND REAC was then set up to simulate the line characteristics. For this purpose the frequency response was approximated analytically by

$$\left(\frac{E_i}{E_o}\right)^2 = \left[1 + \left(\frac{200}{f}\right)^{10}\right]\left[1 + \left(\frac{300}{f}\right)^2\right]\left[1 + \left(\frac{f}{1100}\right)^2\right]^2\left[1 + \left(\frac{f}{2400}\right)^{20}\right]$$

giving the frequency characteristic shown by the solid line in Fig. 1. The response of this network to a step input is shown in Fig. 4A, and the response to a short (2/10 ms) pulse is shown in Fig. 5A. Comparing Fig. 2 with Fig. 4A and Fig. 3 with Fig. 5A, it is seen that the responses are similar but that the telephone line shows more ringing (both high and low frequency) than the REAC approximation.

It was known that the high-frequency cutoff was not well simulated on the REAC, so a new approximation was made using 72 db/octave high-frequency slope

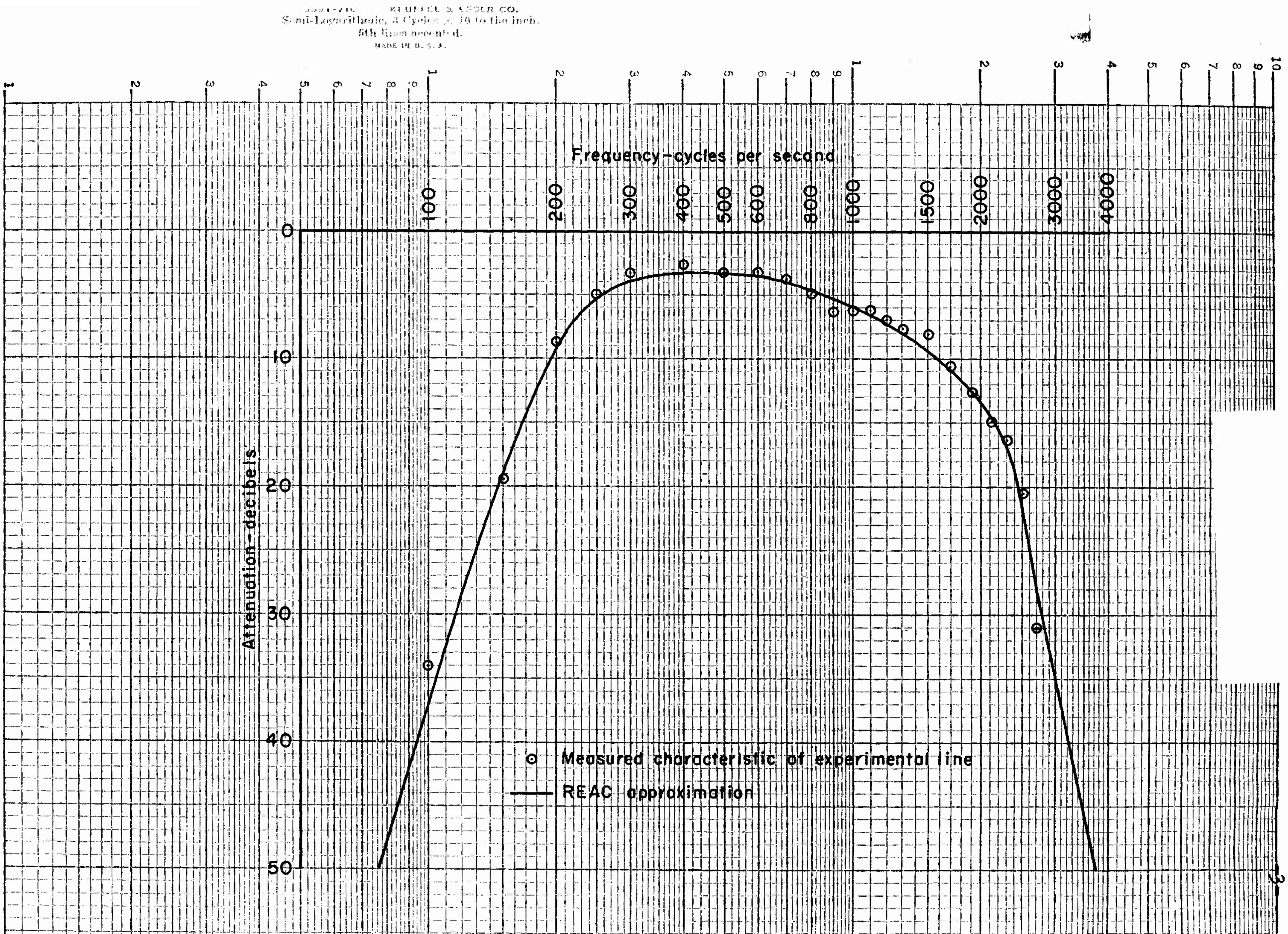

Fig. 1 — Frequency response of experimental line

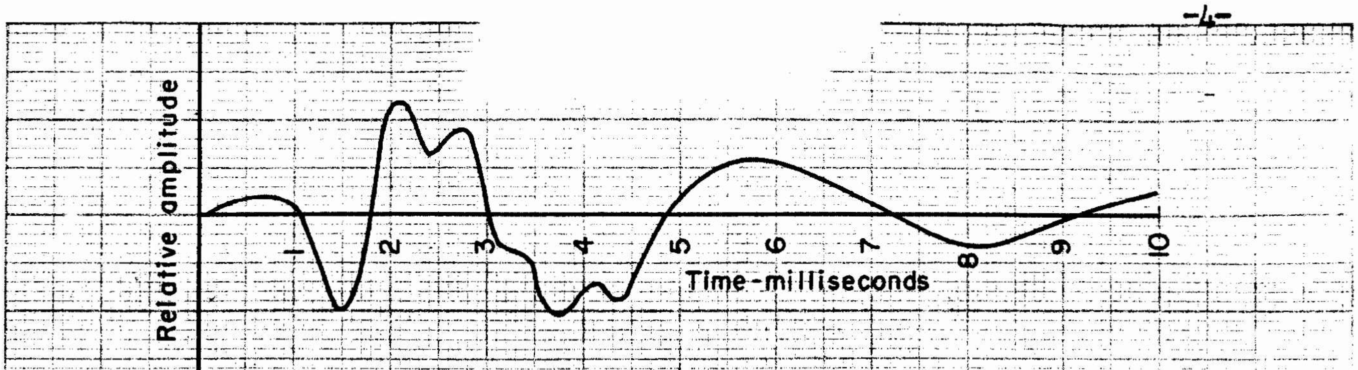

Fig. 2—Response of line to step input

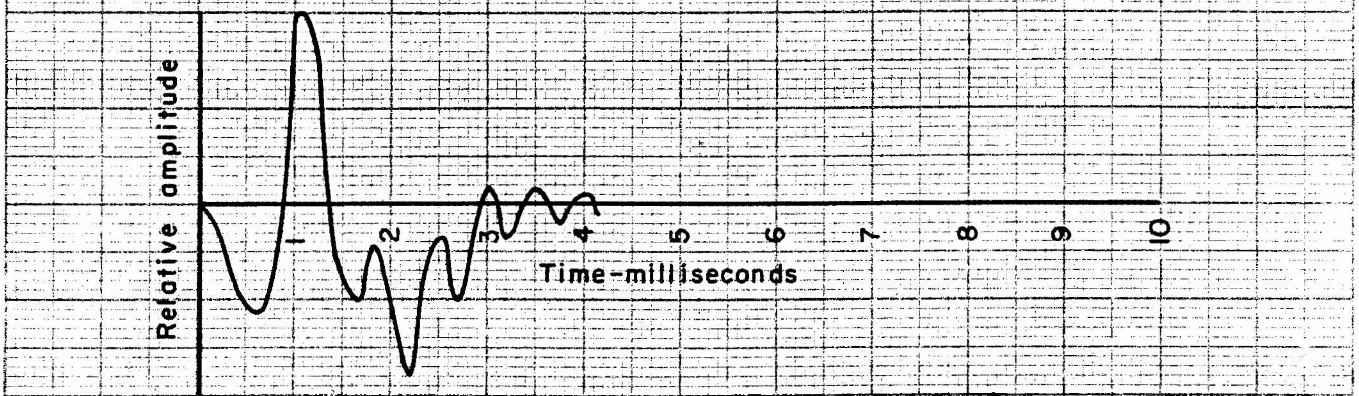

Fig. 3—Response of line to short pulse (1/8 ms)

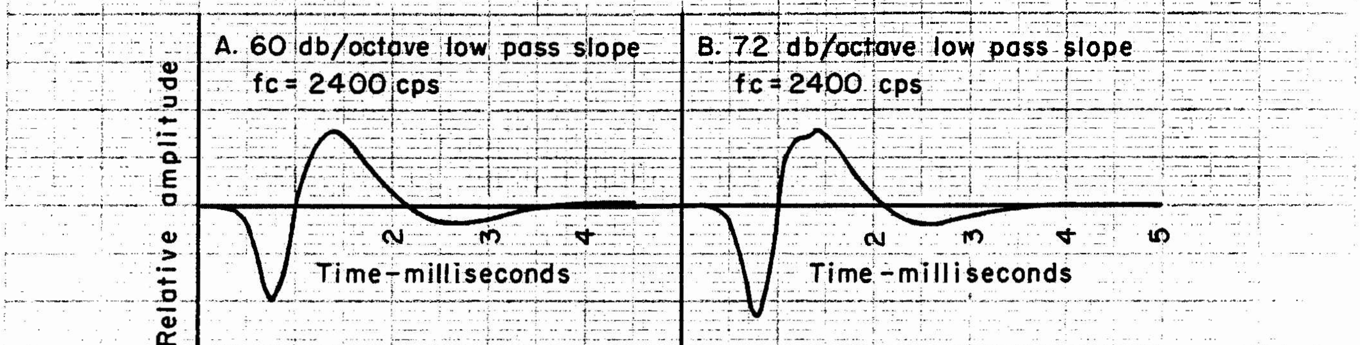

Fig. 4—Response of REAC line to step input

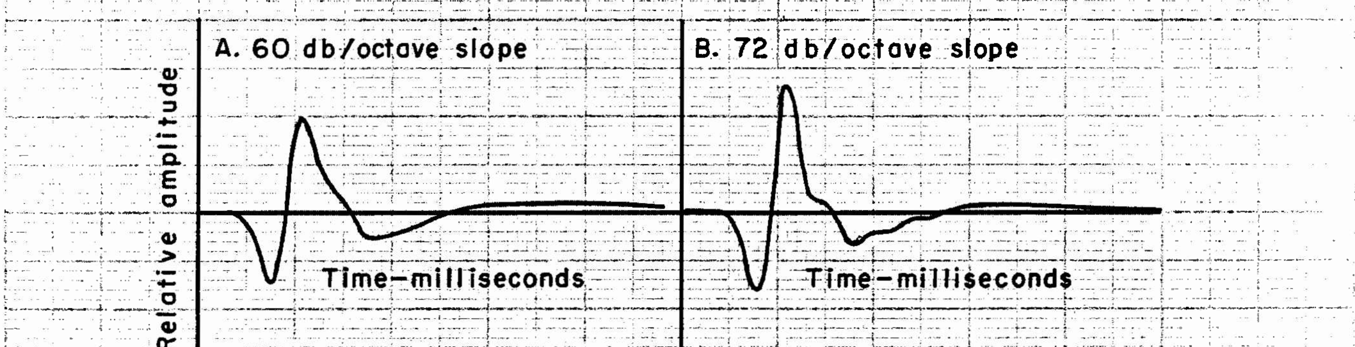

Fig. 5—Response of REAC line to short pulse

in place of the 60 db/octave used in the first approximation (in the analytical expression the exponent 20 in the last term is replaced by 24). The response of the new approximation is shown in Fig. 4B (step input) and Fig. 5B (short pulse). The characteristic high frequency ringing of the real line is evident in this new approximation. Time (and REAC elements) did not allow a new approximation with a still sharper cutoff at 2400 cps, but it may be inferred that not too much additional slope would be required for a good simulation of this characteristic.

No attempt was made to improve the simulation at the low frequencies. Actually, the REAC line cut off too fast below 150 cps so that a somewhat simpler representation would have sufficed (the error became apparent when a more complete frequency run was made). It is reasonable to suppose than an improved simulation of the low-frequency response would yield a REAC network more closely simulating the low-frequency ringing of the actual line.

The REAC network (with 72 db/octave slope from 2400 cps) was considered to adequately represent a "typical" line. This network was then subjected to various types of input signals to find a suitable form for pulse transmission. The response of the network to various length pulses is shown in Fig. 6. To utilize the line most effectively it is necessary that each pulse be confined in time as much as possible. This is seen to require pulses of less than a 1/2 ms duration. Pulses of 2/10 ms duration seem close to the optimum (they behave like impulses). Shorter pulses yield similar outputs but with decreasing amplitude.

The response of the REAC network to 2/10 ms pulses persists longer than is desirable. The persistence can be reduced by cutting down the low-frequency energy in the system. This can be done by passing the signal through a differentiating network. The curves of Fig. 7 correspond to those of Fig. 6, but

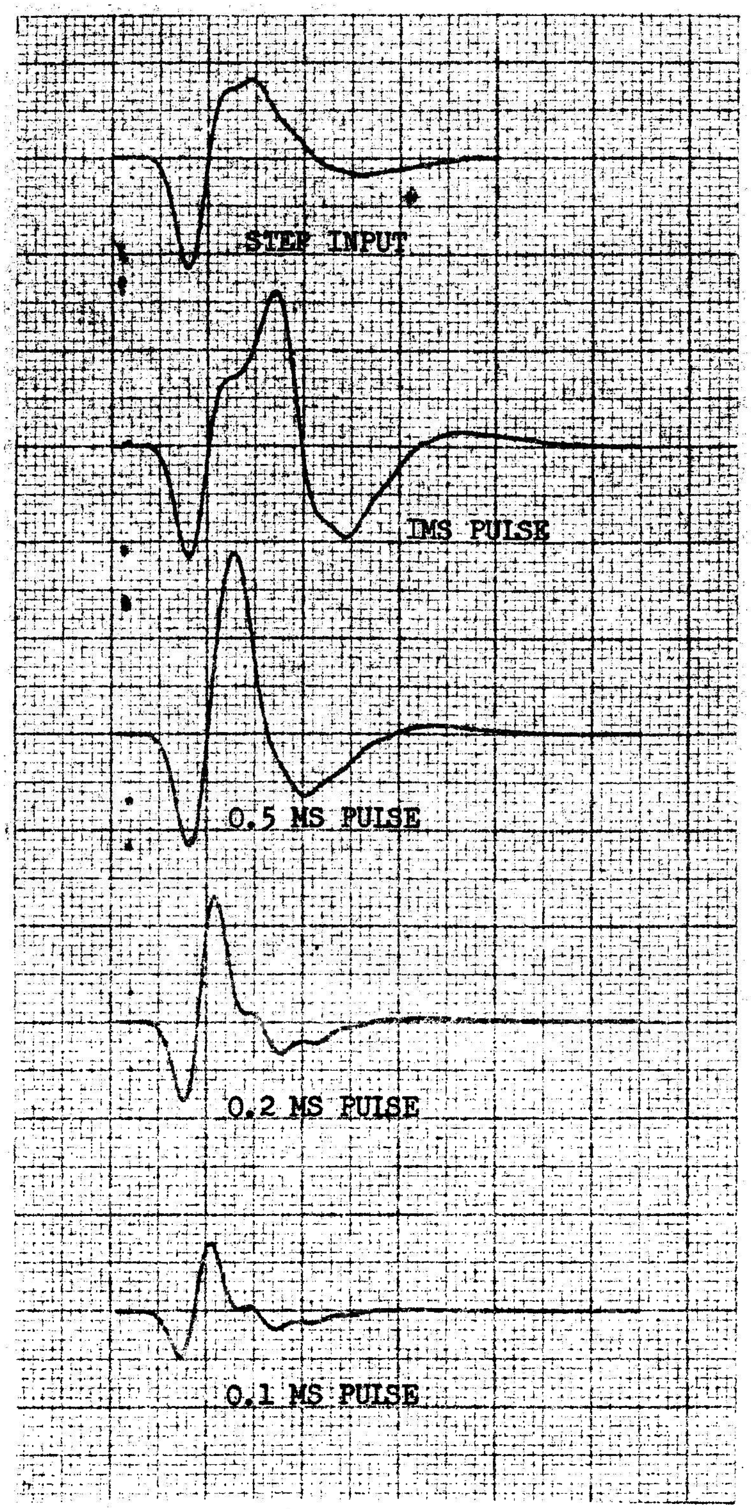

Fig. 6 - Response of Simulated Line to Various Duration Pulses

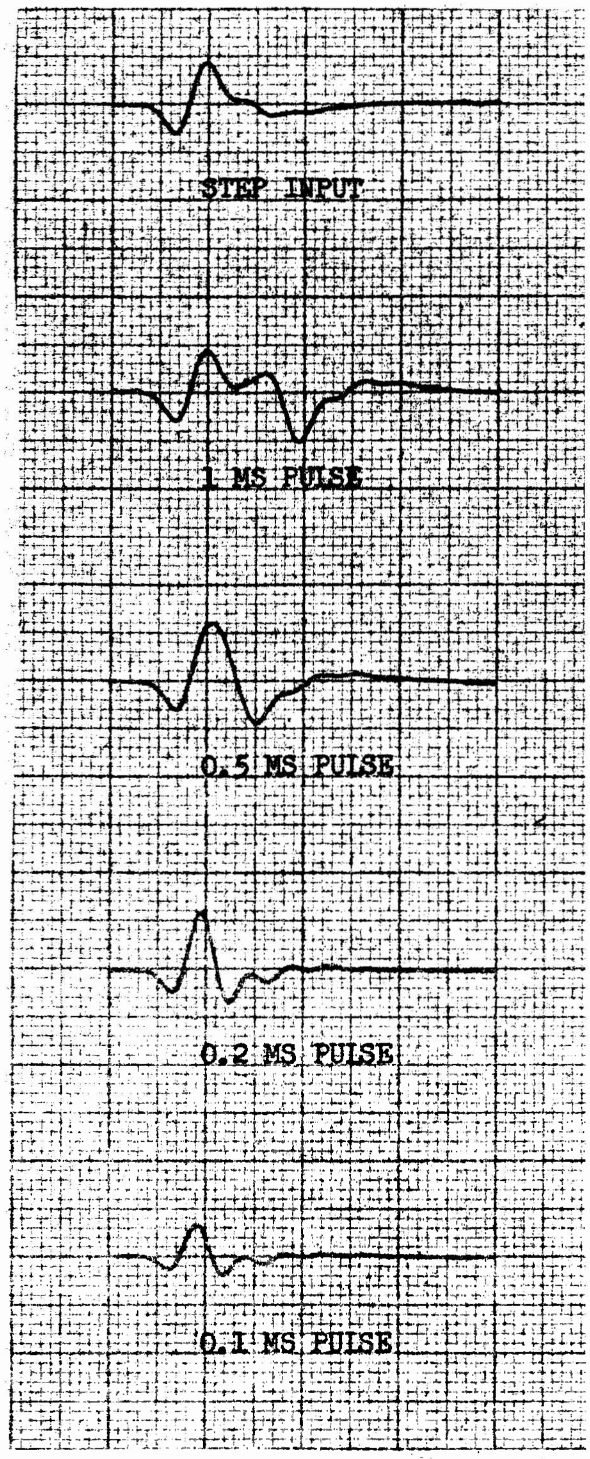

Fig. 7 - Response of Simulated Line with Differentiator to Various Duration Pulses

a high-pass section

$$\left(\frac{E_i}{E_o}\right)^2 = 1 + \left(\frac{2400}{f}\right)^2$$

was added to serve as a differentiating network. The short pulse (2/10 ms) is again seen to be desirable. The differentiator is seen to have produced a marked improvement.

The response of the REAC network with a double-differentiator added was considered to offer some hope of further improvement. For this purpose a high-pass section

$$\left(\frac{E_i}{E_o}\right)^2 = 1 + 4\left(\frac{2400}{f}\right)^2 + \left(\frac{2400}{f}\right)^4$$

was added to the simulated line. The response of the resulting network is shown in Fig. 8.

A suggestion has been made to use an input consisting of one cycle of a sine wave. This was tried with the results shown in Fig. 9. The frequency selected was 2000 cps, just inside the pass band. It is seen that the response of the normal line to the sinusoid is practically the same as the response of the line-plus-differentiator to a 2/10 ms pulse (Fig. 7), while the response of the line-plus-differentiator to the sinusoid is practically the same as the response of the line-plus-double-differentiator to the 2/10 ms pulse (Fig. 8), Since the equipment to generate a synchronized sinusoid is fairly complicated, it is apparent that the differentiated pulse input is to be preferred.

It is of interest to examine the "best" operating condition in more detail. The line-plus-differentiator has the frequency response shown in Fig. 10. The principal effect of the differentiator is seen to have been the removal of the

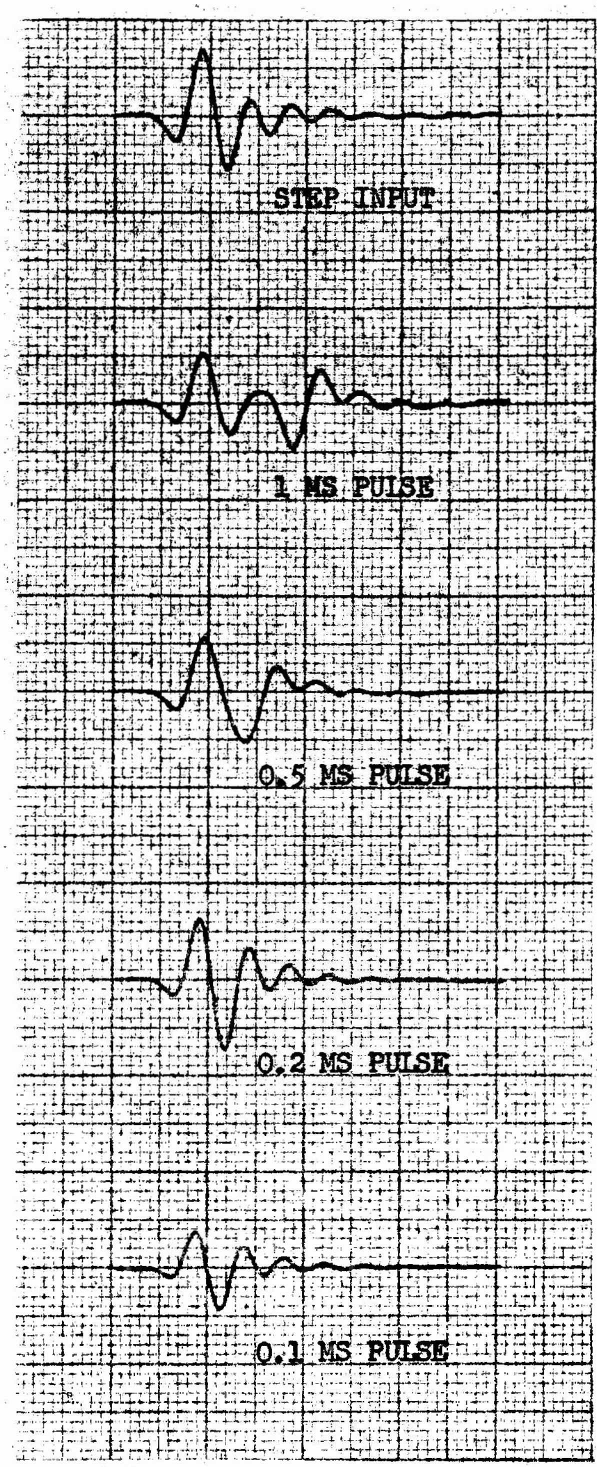

Fig. 8 - Response of Simulated Line with Double-Differentiator to Various Duration Pulses

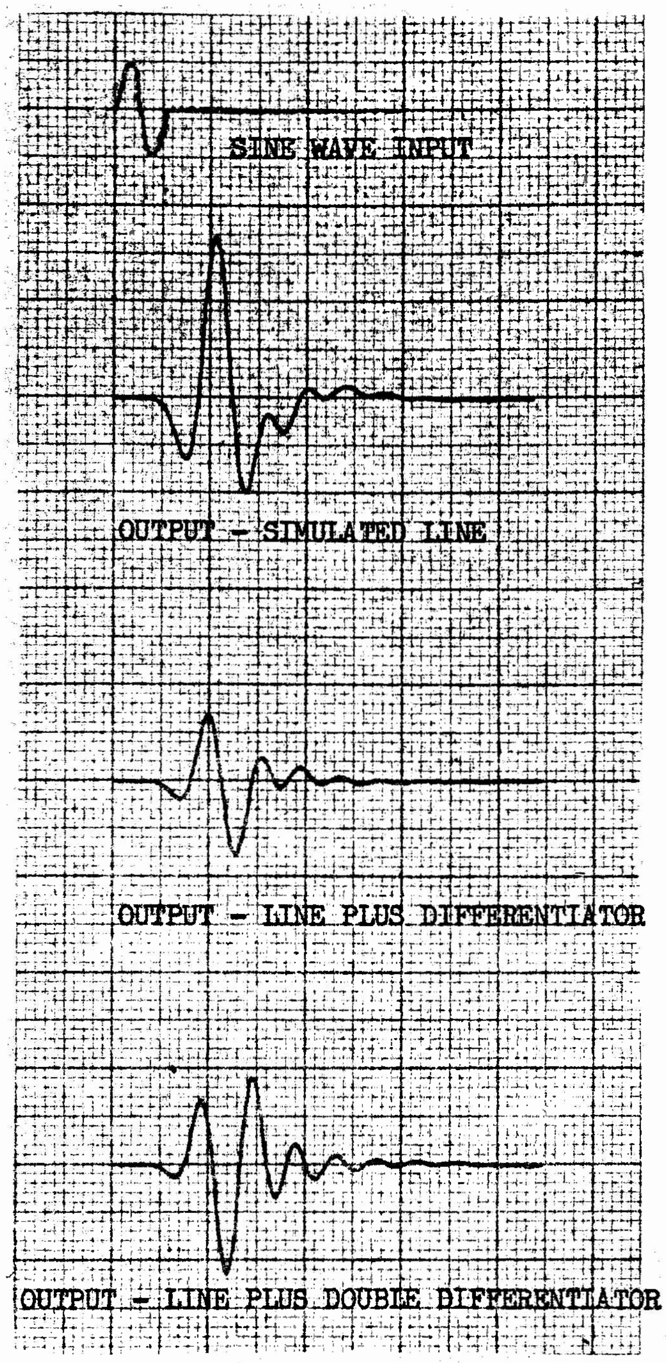

Fig. 9 - One Cycle of Sine Wave (2000 cps) into Simulated Line and Line with Differentiators

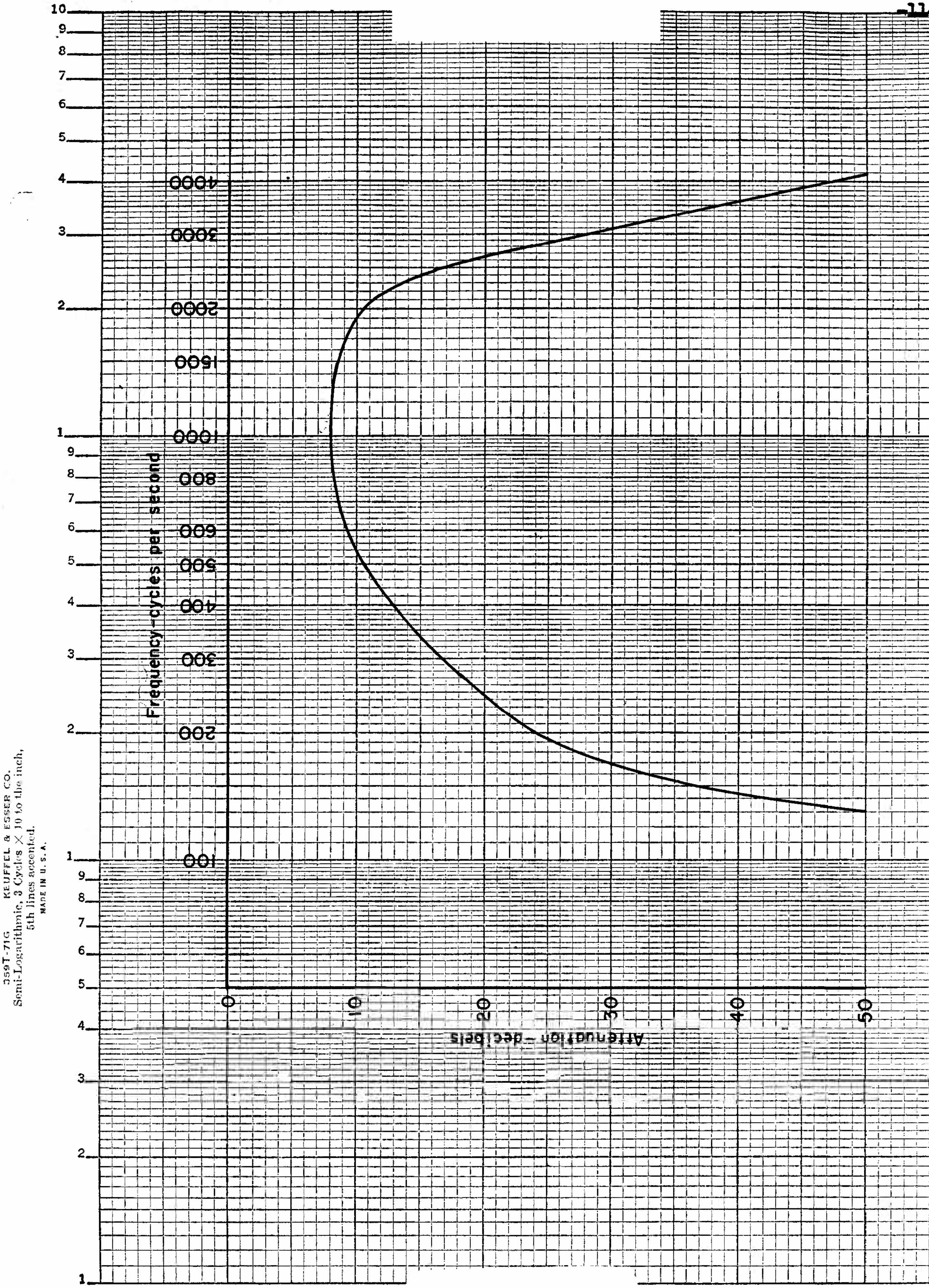

Fig. 10 — Frequency response of simulated line plus differentiator

low-frequency hump. To investigate the speed at which independent pulses can be transmitted, it is necessary to make an assumption with respect to the allowable variation in pulse amplitude. In many cases it is considered desirable to sacrifice amplitude information in favor of higher resolution. The response of the line-plus-differentiator to a pair of equal amplitude pulses of 2/10 ms duration and varying separation is shown in Fig. 11. It is evident that the line operating with differentiator is quite capable of resolving pulses that are as close together as 0.4 ms. While it is possible that the original line (Fig. 3) might not be able to resolve quite as well because of the high-frequency transient, it is likely that simple phase equalization to correct for the effect of the steep high-frequency cutoff would make the line useful to about the same pulse separation.

The equipment necessary to achieve the desired transmission characteristics is quite simple. At the transmitting end the input signal is applied to a toggle circuit such as that shown in Fig. 12.* This is a double

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* "Waveforms," Chance et al, Radiation Laboratory Series, Vol. 19, pg. 349

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triode circuit with direct plate to grid coupling from triode one to two, and adjustable cathode coupling from two to one. With small cathode coupling the

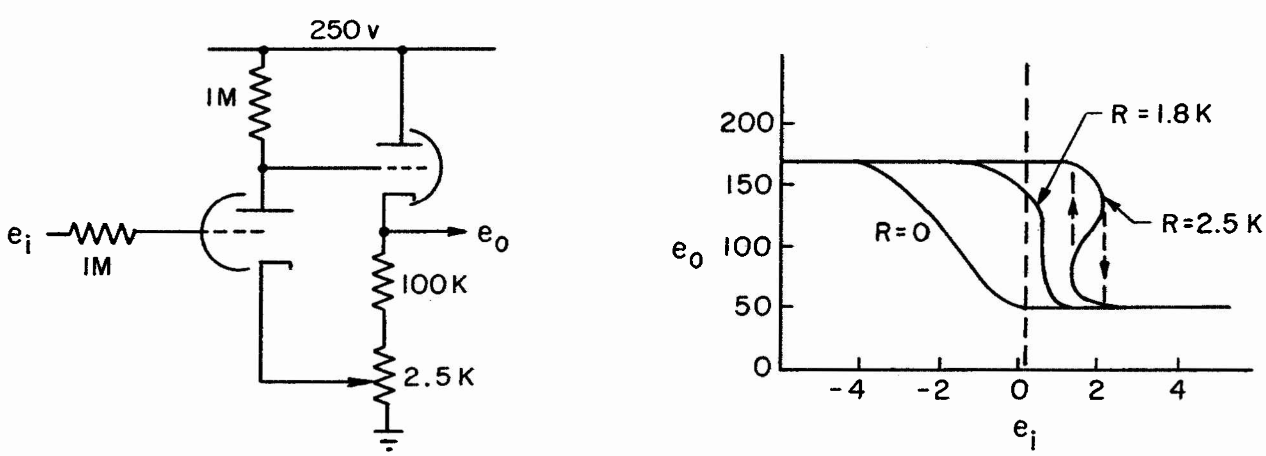

Fig. 12 - Toggle Circuit with Transfer Characteristic

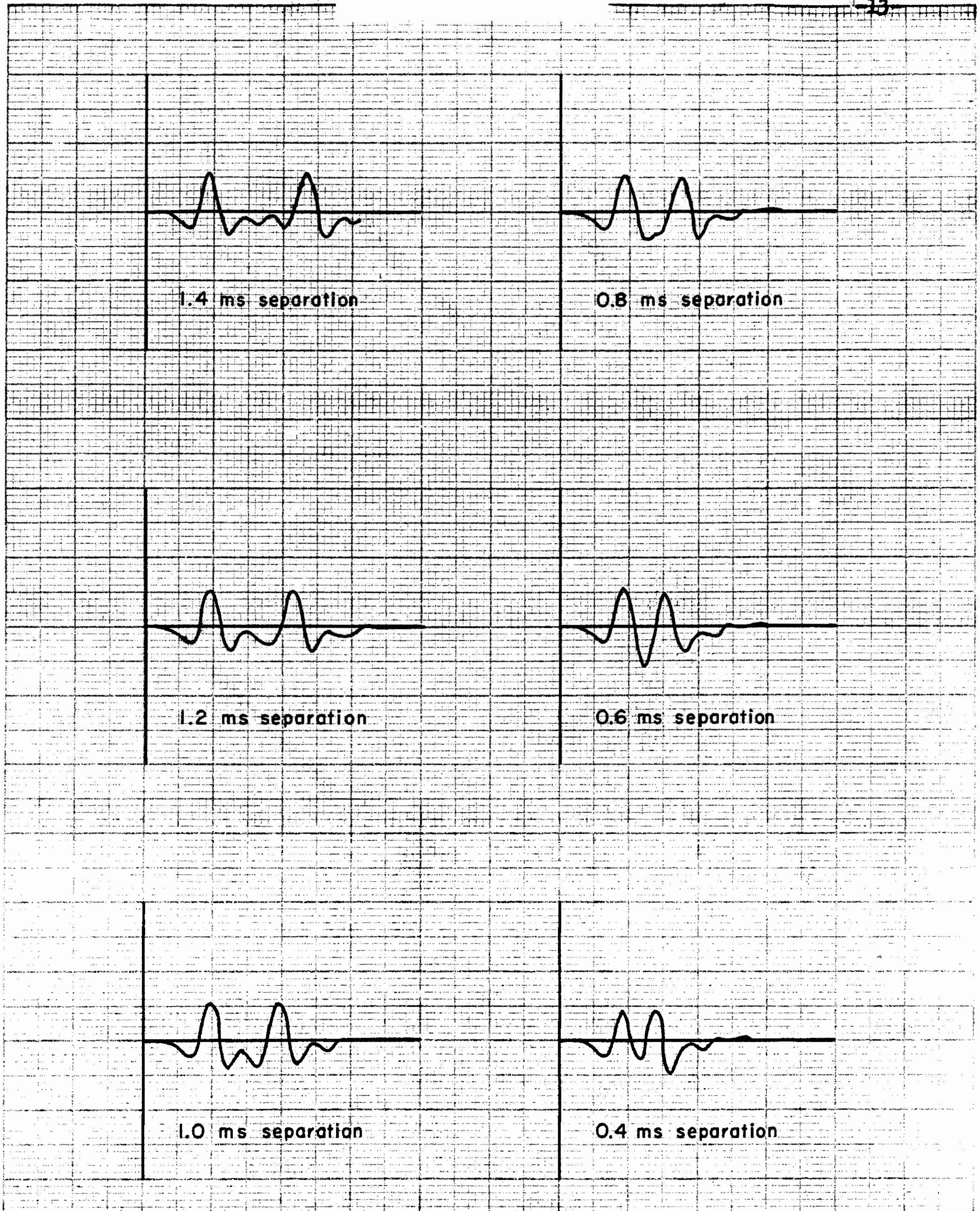

Fig. 11 — Response of simulated line to closely spaced pulses

circuit behaves like a normal amplifier, but with increasing coupling regeneration increases the gain until, with sufficient coupling, a region of instability appears. The curve with R = 2.5K illustrates the toggle action desired for the present application. As the grid goes positive the cathode voltage drops slowly until the grid reaches about two volts positive when the cathode voltage drops abruptly to a low value. As the grid voltage is reduced, the cathode voltage rises gradually until the grid voltage reaches about one volt when the cathode voltage rises abruptly. The action is illustrated in Fig. 13.

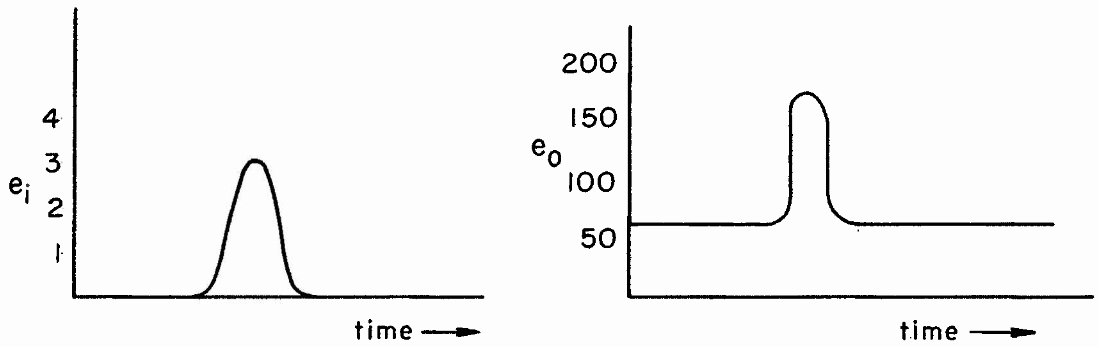

Fig. 13 - Operation of Toggle Circuit

The output of the toggle thus has a standard amplitude but variable duration that is a function of the shape of the input pulse. The discontinuity permits a short-time-constant differentiation to generate the impulse signals desired for the line input (the shape of an impulse signal is unimportant, so the differentiated output suffices). The second impulse (negative to the first) generated by the differentiator is removed by a simple clipping circuit. The output of the clipper is then passed through a second differentiating circuit (to correct for the line response) and the output is used to drive the line.

Since the pulses going into the line contain no amplitude information, the receiving equipment can also be quite simple. The received signal can be amplified and applied to a toggle circuit (similar to that at the transmitter) whose output will then be constant amplitude pulses corresponding to the compressed radar signals. These can then be further processed to produce the desired results.

It may sometimes be desirable to transmit the pulse information over longer lines than that used in the tests. In such cases the line characteristics may not allow adequate pulse resolution. The difficulty could be alleviated by the introduction of restandardizing equipment at one or more intermediate points in the line. Such equipment could be made quite simple and could operate unattended with high reliability.

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